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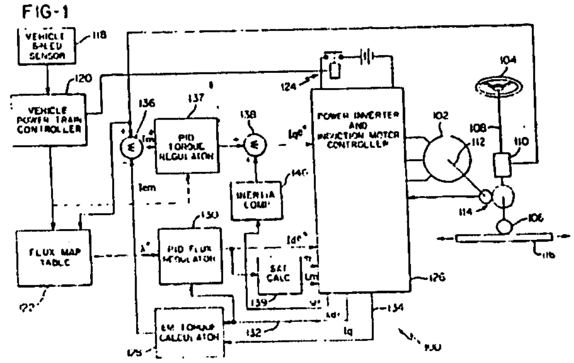
(54) **A power assisted steering system**

(57) Electric motors (102) having controllable induced armature fields, such as induction motors and synchronous reluctance motors, are used in power assisted steering systems for motor vehicles. Power is conserved by tailoring induced armature fields or rotor flux in accordance with the speeds of motor vehicles including the power assisted steering system. In particular, one or more flux programs or maps are provided for the power assisted steering system with the flux map or program being accessed or addressed by means of the vehicle speed. During low speed operation of the motor vehicle, for example to perform parking manoeuvres where speeds are near zero and steering forces are near or at maximum, the rotor flux is programmed to maximum. For high speed operation, such as highway and rural motor vehicle operation, the rotor flux is programmed to a low value so that internal loss mechanisms in the power assist motor and motor controller are minimised yet provide sufficient rotor flux to meet steering needs such as lane changes, obstacle avoidance and the like. Various transition speeds and flux transition curves provide smooth transitions between high flux levels and low flux levels.

FIG-1



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Description

The present invention relates in general to power steering systems using an electric motor to produce auxiliary steering force for augmenting the torque applied to a steering wheel by an operator of a motor vehicle and, more particularly, to the use of electric motors having controllable induced armature fields, such as induction motors and synchronous reluctance motors, and the control of the induced armature fields in such motors to reduce the power consumed by the power steering systems.

Electric power assisted steering (EPAS) is being developed to improve steering control capabilities, reduce system costs and, at least in part, to improve fuel economy over power assisted hydraulic systems. A wide variety of electric motors are available for use in EPAS ranging from permanent magnet brushed and brushless, to switched and synchronous reluctance, to induction motors. Physical size favours the permanent magnet motor while cost favours the reluctance and induction motors. Smoothness of operation also favours synchronous reluctance and induction motors since EPAS should not introduce extraneous "noise" and vibration into the steering wheel and switched reluctance motors tend to have more torque ripple than desired for use in EPAS.

While cost and smoothness of operation favour synchronous reluctance and induction motors over other motors available for EPAS, synchronous reluctance motors and induction motors require the provision of external power to energise or maintain the flux in the armature or rotor of the motor. Accordingly, if synchronous reluctance motors and/or induction motors are to be used for EPAS, there is a need to reduce the energy consumed by these motors for armature or rotor excitation.

The present invention provides a power assisted steering system including an electric motor having controllable induced armature fields, such as an induction motor or a synchronous reluctance motor. Power is conserved by tailoring induced armature fields or rotor flux in accordance with the speed of a motor vehicle including the power assisted steering system. In particular, one or more flux programs or maps are provided for the power assisted steering system with the flux map or program being accessed or addressed by means of the vehicle speed. During low speed operation of the motor vehicle, for example to perform parking manoeuvres where speeds are near zero and steering forces are near or at maximum, the rotor flux is programmed to maximum. For high speed operation, such as highway and rural motor vehicle operation, the rotor flux is programmed to a low value so that internal loss mechanisms in the power assist motor and motor controller are minimised yet provide sufficient rotor flux to meet steering needs such as lane changes, obstacle avoidance and the like. Various transition speeds and flux transition curves provide smooth transitions between high flux levels and low flux levels.

In accordance with one aspect of the present invention, a motor driven power assisted steering system for a motor vehicle comprises an electric motor with a controllable induced armature field. A coupler mechanism couples an output shaft of the electric motor to steering gear of a motor vehicle which includes a vehicle speed sensor for detecting the operating speed of the motor vehicle and for generating representative speed signals. A motor controller responsive to the speed signals controls the induced armature field of the electric motor as a function of the operating speed of the motor vehicle. The electric motor may be an induction motor or a synchronous reluctance motor.

The present invention provides an improved power assisted steering for motor vehicles wherein power assistance is provided by electric motors having controllable induced armature fields and to reduce power consumption in those motors by programming induced armature fields or rotor flux in accordance with the speeds of motor vehicles including the power assisted steering systems.

The invention will now be described further, by way of example, with reference to the accompanying drawings, in which:

Fig. 1 is a schematic block diagram of an electric power assisted steering (EPAS) system for a motor vehicle in accordance with the present invention;

Fig. 2 is a graph of flux programs or maps and a steering torque curve for the EPAS system of Fig. 1;

Fig. 3 is a schematic block diagram of a portion of the power inverter and induction motor controller of Fig. 1;

Fig. 4 is a vector diagram illustrating the three phase stator currents of Fig. 5;

Fig. 5 is a graph of three phase stator currents in an induction motor; and

Fig. 6 is a graph illustrating two slip curves for the induction motor of Fig. 1.

Reference is now made to Fig. 1 which schematically illustrates an electric power assisted steering (EPAS) system 100 including speed tracking of an induced armature field in a motor 102 which performs steering assistance. The motor 102 has a controllable induced armature field, currently an induction motor is preferred and the invention will be described with reference to an induction motor; however, a synchronous reluctance motor can also be used in the present invention. The system 100 includes a steering wheel 104 which is operatively connected to a pinion gear 106 via a steering shaft 108. A torque sensor 110 is coupled to the steering shaft 108 to measure the torque Tstr applied to the steering wheel 104 by an operator of the motor vehicle including the system 100.

The motor 102 includes an output shaft 112 which

is coupled to the steering shaft 108 via a gear set 114. The pinion gear 106 which is driven by the steering shaft 108, engages and drives a linear steering member or rack 116 which is connected to steerable wheels (not shown) in a conventional manner.

A conventional vehicle speed sensor 118, coupled to a transmission or one or more of the wheels of the vehicle including the system 100, generates vehicle speed information signals which are connected to a vehicle power train controller 120. The power train controller 120 processes the vehicle speed information signals to generate speed dependent address signals for a flux map table 122 which includes at least one speed dependent flux program or map for operation of the motor 102 as will be described

The controller 120 also generates a power steering command signal which operates a relay 124 to activate or deactivate the EPAS system 100 by connecting or disconnecting power from a power inverter and induction motor controller 126. This allows the EPAS system 100 to operate with the ignition off or the engine stalled unlike hydraulic systems which it replaces. In addition, it permits the vehicle power train controller 120 to disconnect the EPAS system 100 in the event of failure within tho systom 100.

The power inverter and induction motor controller 126 includes sensors for determining the flux waveform λdr in the rotor of the motor 102, the quadrature current Iq and/or for monitoring the speed ωr and the torque Tr of the output shaft 112 of the motor 102 via sensors associated with the gear set 114 or otherwise associated with the motor 102 or the output shaft 112. The flux waveform λdr is passed to an electromagnetic (EM) torque calculator 128 and a proportional-integral-derivative (PID) flux regulator 130 via a conductor 132. The PID flux regulator generates a flux command signal I_d^{e*}

The EM torque calculator 128 also receives the quadrature current Iq via a conductor 134. To determine the EM torque, the torque calculator 128 executes the function:

$$Tem = (3/2)\ (P/2)\ (Lm/Lr)\lambda drIq\ (Nm)$$

where P is the number of poles of the motor 102, Lm is the magnetising inductance of the motor 102 and Lr is the rotor inductance of the motor 102. No friction effects are included in the Em torque calculator.

The torque Tstr applied to the steering wheel 104 by an operator of the motor vehicle including the system 100 as sensed by the torque sensor 110 is passed to a summer 136. The summer 136 also receives the EM torquo Tom calculatod by tho EM torquo calculator 128 and subtracts the EM torque Tem from the sensed torque Tstr. The resulting error signal is passed to a PID torque regulator 137 which generates a requested torque signal and passes it to a summer 138.

A saturation calculator 139 estimates a rotor flux time constant Tr = Lr/Rr, i.e., rotor inductance over rotor resistance and magnetising inductance Lm based on the equation:

$$\lambda dr(Id^{e*}) = a1(1 - \exp(-a2{*}Id^{e*}))$$

$$Lm = \lambda dr(Id^{e*})/Id^{e*}$$

$$\tau r = Lr(Id^{e*})/R2$$

where a1 and a2 are constants and R2 is temperature dependent resistance of the rotor. For a 500 watt induction motor used in a working embodiment of the present invention, a1 = 0.05, a2 = 0.035 and R2 = 0.018 @ 25°C. It is noted that the estimates generated by the saturation calculator 139 are used by the EM torque calculator 128.

An inertia compensator 140 receives the speed ωr of the output shaft 112 of the motor 102 to generate a signal representative of the inertia of the rotor of the motor 102 which is coupled to tho steoring shaft 108 via tho gear set 114. The presence of the rotor inertia will be felt in the steering wheel 104 just as the added inertia of an air bag in the steering wheel 104. The inertia compensator 140 uses estimated rotor acceleration which is derived by taking the derivative of the estimated rotor speed, i.e., the speed ωr of the output shaft 112 of the motor 102, and multiplies the estimated rotor acceleration by motor inertia with the result being added to the requested torque signal by the summer 138 to generate the torque command signal I_q^{e*} which is passed to the power inverter and induction motor controller 126.

Basic operating control of the motor 102, whether an induction motor as illustrated or a synchronous reluctance motor, is in accordance with well known operating techniques such as field orientation control and various scalar control methods so that only the power inverter and induction motor controller 126 of Fig. 1 will be further described herein for clarification of the invention of the present application. In accordance with the present invention, the induced field of the armature or rotor of the motor 102 is controlled in accordance with a speed dependent flux program or map contained within the flux map table 122.

By using an induction motor or synchronous reluctance motor in the EPAS system, constant excitation of the motor armature or rotor is required via a power inverter in order to maintain the rotor flux level active and roady for instant rosponso. It is important to maintain a high flux level at low speed for example to assist in parking and other low speed manoeuvres. At high speeds, a high flux level is not required. Since a small motor of 200 to 500 watts at the shaft can be used in the EPAS system 100 and such motors have small rotor flux time constants on the order of 30 to 90 milliseconds, in ac-